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Factors affecting CO₂ intensities of power sector in Asia: A Divisia decomposition analysis

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Abstract

This paper analyses the evolution of CO₂ intensity of the electricity sector in 12 selected Asian countries during the period 1980–90. The roles of changes in generation mix and fuel intensity in CO₂ intensity changes during the period have been examined using Divisia index decomposition approach. A key finding of this study is that power sector CO₂ intensities of most Asian countries were mainly influenced by changes in fuel intensities during 1980–90.

JEL Classification: Q40

Keywords: CO₂ intensity; Generation mix; Fuel intensity

1. Introduction

The electricity sector accounts for a substantial share in total carbon dioxide (CO₂) emissions from the Asian region. Its share was estimated to vary from 10 to 40% of total national CO₂ emission from commercial energy consumptions in Asian countries in 1987 (Shrestha and Acharya, 1992). CO₂ emission intensity (defined as the amount of carbon emitted per unit of thermal electricity generation) decreased in most of Asian countries and increased slightly in a few countries during 1980–90. It is well known that the level of CO₂ intensity of the electricity sector can depend upon generation mix (i.e. fuel share in power generation), quality of fuel used (i.e. heat value, carbon content) and generation efficiency of

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thermal power plants. An analysis of the contribution of each of these factors on CO₂ emission intensity from the power sector could be of interest not only for understanding the historical evolution of the CO₂ intensity but also in identifying the appropriate strategies for mitigation of CO₂ emissions from the power sector in individual countries.

There are a number of studies examining the factors (i.e. improvement in energy efficiency and structural change) affecting energy intensity in the manufacturing sector (see e.g. Ang, 1994; Gardner, 1993; Boyd et al., 1987; Hankinson and Rhys, 1983; Huang, 1993; Li et al., 1990). On the other hand, there are only a few studies that discuss the relative contributions of individual factors to the change in CO₂ emission intensities in the literature. Torvanger (1991) and Ogawa (1990) are perhaps the only studies in this direction so far. However, these studies deal with the issue of CO₂ intensity of more aggregated sectors. None of these papers has examined the factors affecting CO₂ intensity in the case of electricity sector.

This paper examines the roles of changes in generation mix and fuel intensity to the changes in CO₂ intensity of thermal power generation in 12 selected Asian economies: China, Hong Kong, India, Indonesia, Japan, Malaysia, Pakistan, Philippines, Singapore, South Korea, Taiwan and Thailand during 1980–90. The distinctive features of the present study are mainly twofold. First, it analyses the effects of changes in fuel intensity and generation mix on the change of power sector CO₂ intensity of both industrialized and developing countries of Asia. Furthermore, to the knowledge of the authors, this is the first study that has examined the effects of generation mix and fuel intensity changes on the evolution of CO₂ emission intensity in electric power sector using the divisia decomposition approach.

2. Overview of Asian power sector

The electricity sector in Asian countries has been subjected to a significant change in its structure during 1980–90. The share of thermal generation was decreasing in most of the Asian countries during 1980–90 as shown in Table 1.

As can be seen from Table 1, the thermal share was decreasing rapidly in South Korea and Taiwan, moderately in Malaysia, Philippines and Japan and only slightly in China, Indonesia and Thailand during the period. Conversely, the thermal share was increasing in India and Pakistan. The growth of nuclear power generation was responsible for the decline in thermal share in the case of South Korea, Taiwan and Japan. In the rest of the countries, the decline can be attributed to hydro power generation.

Coal and fuel oil are the main fuels used for thermal power generation in Asia. However, rapid fuel substitution has been taking place in the power sector of most countries in the region. Table 2 shows that the share of fuel oil and diesel based generation decreased while that of coal and natural gas based generation increased in most countries during the study period.

In the early 1980s, coal was used for power generation in only 7 out of the 12 countries under this study while by 1990, all selected countries except Singapore

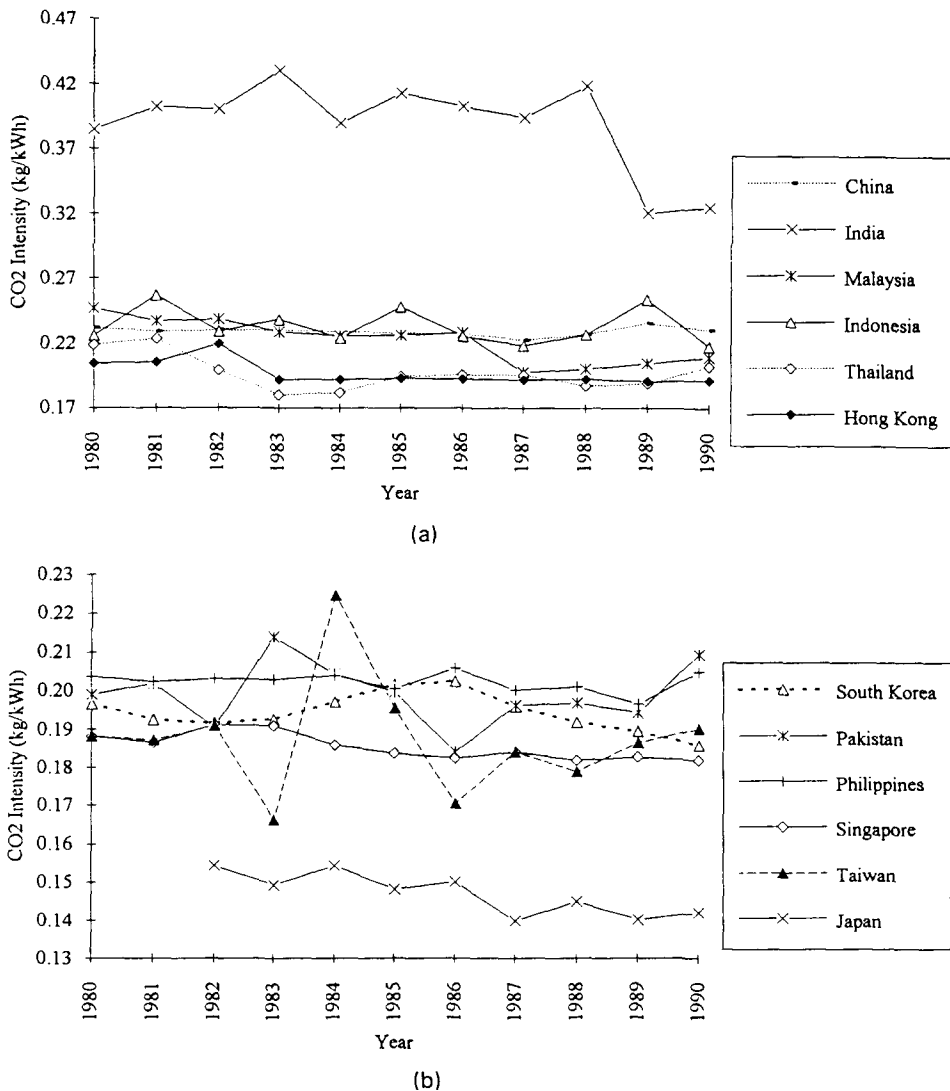


Fig. 1. Changes in power sector CO₂ intensity in selected Asian countries.

were using coal in the power generation. In addition, the share of coal-fired power generation increased substantially in all of the countries except India during 1980–90. Similarly, the share of natural gas was also increasing in most of the industrialized Asian economies (e.g. Japan, Taiwan, Malaysia, Thailand and South Korea) during the period. However, in the case of Pakistan, where the share of natural gas based generation was substantially high in early 1980s, the share was non-increasing during 1980–90.

Table 1

The share of thermal electricity generation in total generation

Country/region	Share (%)	
	1980	1990
China	80.6	79.7
Hong Kong	100.0	100.0
Korea	85.9	45.1
Taiwan	73.9	52.0
India	55.3	75.5
Pakistan	41.4	55.0
Indonesia	82.1	80.0
Malaysia	91.0	84.6
Phillipines	63.0	54.1
Singapore	100.0	100.0
Thailand	94.0	92.3
Japan	67.7 ^a	65.0

^a1982 figure.

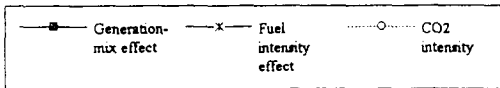
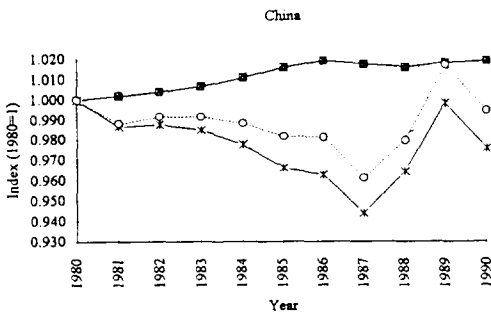
Source: ADB (1993); IEA (1993).

Fuel intensity in selected Asian countries for years 1980 and 1990 are shown in Table 3. Fuel intensities (kg/kWh) of coal and diesel based electricity generation were decreasing in most of the countries indicating improvements in efficiency of power generation based on these fuels. The intensities of fuel oil based generation had either increased or remained unchanged during the period.

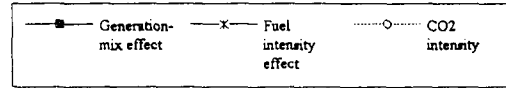
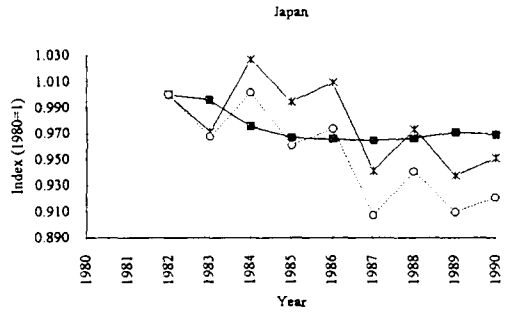
3. Methodology

To present the methodology used in this study, we first define the following symbols:

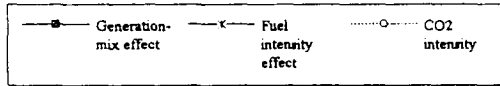
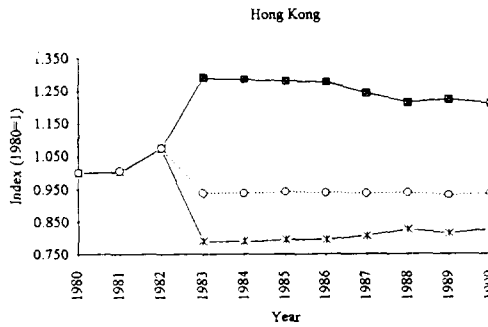
- e_t = CO₂ emission intensity of thermal power generation in year t
- E_t = total CO₂ emissions from thermal power generation for year t
- E_{it} = emission of CO₂ from power generation based on fuel type i in year t
- C_{it} = carbon content of fuel type i (expressed as a fraction of total weight of fuel) in year t
- k = conversion factor (from carbon to carbon dioxide)
- F_{it} = amount of fuel type i used for power generation in year t
- Q_{it} = electricity generation based on fuel type i in year t
- Q_t = total thermal electricity generation in year t
- f_{it} = fuel intensity of power generation based on fuel type i in year t (= F_{it}/Q_{it})
- g_{it} = share of electricity generation from fuel type i in year t (= Q_{it}/Q_t)



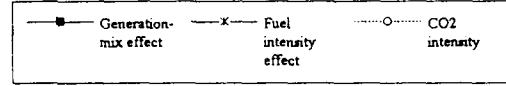
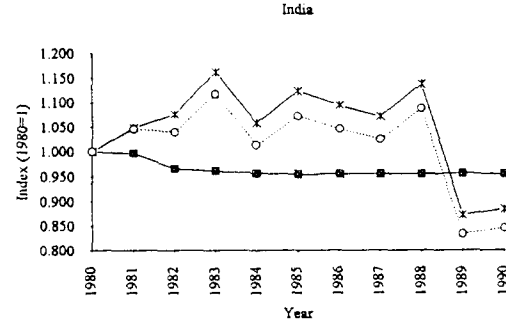
(g)



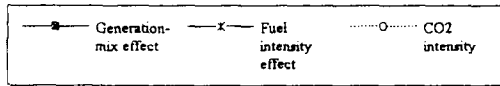
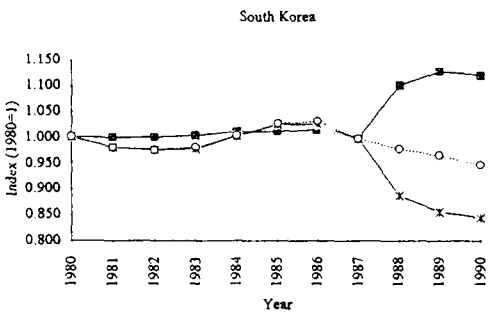
(h)



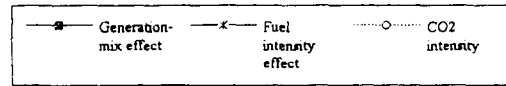
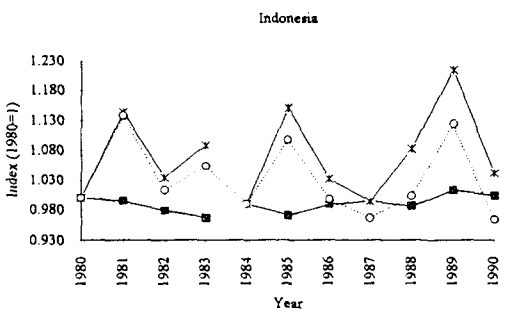
(i)



(j)



(k)



(l)

Fig. 2. Decomposition of power sector CO₂ intensity changes in Asian countries.

Table 2
Generation mix in power sector of selected Asian economies

Country /region	1980					1990				
	Total generation (GWh)	Share (%)				Total generation (GWh)	Share (%)			
		Coal	Fuel oil	Diesel	Gas		Coal	Fuel oil	Diesel	Gas
China	242 417	73.1	25.1	1.3	0.5	494 970	89.9	8.1	1.4	0.6
Hong Kong	9 040	0.0	99.9	0.1	0.0	28 629	99.4	0.5	0.1	0.0
India	61 300	99.0	0.1	0.0	0.9	193 159	97.1	0.1	0.0	2.8
Indonesia	6 157	0.0	63.4	36.6	0.0	27 211	42.6	36.1	17.7	3.6
South Korea	30 175	14.4	84.2	1.4	0.0	46 561	48.2	24.3	2.3	25.3
Malaysia	7 807	0.0	86.6	13.1	0.3	18 709	16.8	47.8	6.0	29.4
Pakistan	6 154	0.5	2.0	0.9	96.6	20 720	0.3	30.6	8.7	60.4
Philippines	9 507	0.0	96.5	3.5	0.0	13 579	12.8	71.9	15.3	0.0
Singapore	6 940	0.0	99.9	0.1	0.0	15 398	0.0	97.0	3.0	0.0
Taiwan	31 482	18.9	77.8	3.3	0.0	44 401	48.8	41.3	7.4	2.5
Thailand	13 154	10.7	86.3	3.0	0.0	39 200	28.2	25.5	0.9	45.4
Japan	393 616 ^a	16.8	63.1	0.0	20.1	557 423	22.1	48.2	0.0	29.7

Sources: ADB (1992, 1993); AEEMTRC (1994); IEA (1993).

^a1982 figure.

Table 3
Fuel intensity of power generation in selected Asian economies

Country /region	Coal (kg/kWh)		Fuel Oil (kg/kWh)		Diesel (kg/kWh)		Natural gas (kgoe/kWh)	
	1980	1990	1980	1990	1980	1990	1980	1990
China	0.62	0.60	0.25	0.26	0.25	0.26	0.67	0.69
Hong Kong	–	0.35	0.25	0.68	0.60	0.50	–	–
South Korea	0.38	0.38	0.25	0.32	0.24	0.21	–	0.16
Taiwan	0.42	0.36	0.22	0.26	0.24	0.04	–	0.23
India	0.66	0.56	0.43	0.42	0.47	0.44	0.85	1.09
Singapore	–	–	0.23	0.23	–	0.27	–	–
Pakistan	0.66	0.65	0.28	0.28	0.27	0.27	0.31	0.32
Indonesia	–	0.40	0.25	0.25	0.31	0.29	–	0.29
Malaysia	–	0.41	0.31	0.32	0.28	0.10	1.32	0.25
Philippines	–	0.47	0.26	0.26	0.17	0.26	–	–
Thailand	0.94	0.89	0.25	0.24	0.41	0.39	–	0.24
Japan	0.31 ^a	0.28	0.20 ^a	0.19	–	–	0.21 ^a	0.19

^a1982 figure.

The total CO₂ emission intensity in year t is expressed as:

$$e_t = \frac{E_t}{Q_t} \quad (1)$$

$$e_t = \sum_i \frac{E_{it}}{Q_{it}} \cdot \frac{Q_{it}}{Q_t} \quad (2)$$

$$e_t = \sum_i k \cdot \frac{c_{it} \cdot F_{it}}{Q_{it}} \cdot \frac{Q_{it}}{Q_t} \quad (3)$$

$$e_t = \sum_i k \cdot c_{it} \cdot f_{it} \cdot g_{it} \quad (4)$$

Following the procedure similar to that of Boyd et al. (1987), the changes in electricity sector CO₂ intensity can be decomposed into three components, i.e. effect due to changes in fuel intensity, generation mix and fuel quality as:¹

$$\ln \frac{e_t}{e_{t-1}} = \sum \tilde{w}_{it} \cdot \ln \frac{f_{it}}{f_{it-1}} + \sum \tilde{w}_{it} \cdot \ln \frac{g_{it}}{g_{it-1}} + \sum \tilde{w}_{it} \cdot \ln \frac{c_{it}}{c_{it-1}} \quad (5)$$

with,

$$\tilde{w}_{it} = \frac{w_{it} + w_{it-1}}{2} \quad \text{and} \quad w_{it} = c_{it} \cdot f_{it} \cdot g_{it} / \left(\sum_{i=1}^n c_{it} \cdot f_{it} \cdot g_{it} \right)$$

where $\tilde{w}_{it}$ = average weighting factor of fuel i in year t and $t - 1$.

Eq. (5) represents the Divisia decomposition of CO₂ intensity of power sector in the general form. The first term in the right-hand side (RHS) of the equation represents the effect due to changes in fuel intensities (e.g. improvements in generation efficiencies of power plant) on the sectoral CO₂ intensity changes (hereafter ‘fuel intensity effect’). The second term in the RHS expresses the effect of changes in generation mix (hereafter ‘generation mix effect’) while the third term denotes the effect of changes in fuel qualities (hereafter ‘fuel quality effect’). The quality of a fuel (i.e. type, heat value and carbon content) can vary across the supply sources. However, in the present analysis, fuel quality is assumed to be unchanged during the study period, mainly for two reasons: First of all, the time series data on fuel quality are not fully available for most of the countries, and second, the quality of petroleum products (i.e. fuel oil, diesel) is unlikely to change significantly in the countries during the period. Similarly, coal quality is unlikely to have changed during the period. This is because, in countries with a high share of coal in power generation, like China, India, Thailand and Indonesia, coal is supplied chiefly from the same set of domestic coal mines. In the case of coal importing countries, the supply sources do not seem to have changed significantly during the period. The foregoing assumption of constant fuel quality implies:

$$\sum \tilde{w}_{it} \cdot \ln \frac{c_{it}}{c_{it-1}} = 0$$

¹Unlike in the present study, the subject matter of Boyd et al. (1987) was, however, to analyse the roles of factors affecting the changes in overall manufacturing sector energy intensity (such as structural change in manufacturing sector and energy efficiency improvements).

Thus, Eq. (5) can be rewritten as:

$$\ln \frac{e_t}{e_{t-1}} = \sum \tilde{w}_{it} \cdot \ln \frac{f_{it}}{f_{it-1}} + \sum \tilde{w}_{it} \cdot \ln \frac{g_{it}}{g_{it-1}} \quad (6)$$

It is to be noted here that Eq. (5) is derived assuming no change in the types of fuel used in power generation during the study period. However, this is not always the case. In some of the countries in the study (e.g. Hong Kong, Indonesia, Malaysia, Thailand, South Korea and Taiwan), power generation from additional fuel types had started in intermediate years during 1980–1990, thus causing discontinuous jumps in time series data of power generation based on such fuels. Such a discontinuity in data has been handled by carrying out separate decompositions for periods before and after the point of discontinuity. The magnitude of fuel intensity – and generation mix – effects before and after the point of ‘discontinuity’ would not be strictly comparable. However, this approach would still allow us to assess the relative contributions of individual factors on CO₂ emission intensity changes.

The data used for this study are based on ADB (1992, 1993) AEEMTRC (1994) and IEA (1993).

4. Results and discussions

4.1 Evolution of CO₂ intensity of power generation

The CO₂ intensities of power sector in the selected countries/regions are shown in Figs. 1(a) and 1(b). As can be seen from the figures, Japan had the lowest CO₂ intensity among the selected economies while India had the highest. The intensity recorded a decreasing trend in Japan, Singapore, Malaysia and Hong Kong while it remained almost unchanged in China and the Philippines. In the case of South Korea and Thailand, the intensity declined during 1980–1983, increased until 1986 and again decreased thereafter. However, both countries maintained an overall declination of CO₂ intensity during the study period. In the rest of the countries, CO₂ intensities exhibited an erratic trend.

CO₂ intensities of power generation for each type of fuel for the selected countries in years 1980 and 1990 are presented in Table 4. Carbon emission per kilowatt hour of electricity in most Asian countries was found to be in the range of 0.18 to 0.26 kg. The emission intensity of coal based power generation declined in most of the Asian countries while that of the fuel oil based generation either increased or remained constant during the period.

4.2 Roles of fuel intensity – and generation mix – effects

The fuel intensity and generation mix effects of individual economies as well as the total power sector CO₂ intensity are presented in Figs. 2(a) to 2(1). The decomposition of CO₂ intensity into fuel intensity and generation mix effects

Table 4

CO₂ intensity (kg/kWh) of electricity sector in selected Asian economies^a

Country /regions	1980					1990				
	Coal	Fuel oil	Diesel	Gas	Total	Coal	Fuel gas	Diesel	Gas	Total
China	0.24	0.20	0.22	0.42	0.23	0.24	0.20	0.23	0.44	0.23
Hong Kong	–	0.20	0.52	–	0.20	0.19	0.54	0.44	–	0.19
India	0.36	0.34	0.41	0.54	0.38	0.30	0.34	0.38	0.49	0.33
Indonesia	–	0.20	0.27	–	0.23	0.22	0.20	0.25	0.18	0.22
Japan	0.16 ^b	0.16 ^b	–	0.13 ^b	0.15 ^b	0.14	0.16	–	0.12	0.14
South Korea	0.19	0.20	0.21	–	0.20	0.19	0.26	0.18	0.10	0.19
Malaysia	–	0.25	0.24	0.83	0.25	0.20	0.26	0.09	0.16	0.20
Pakistan	0.26	0.22	0.24	0.20	0.20	0.26	0.22	0.23	0.20	0.21
Philippines	–	0.21	0.14	–	0.20	0.18	0.20	0.23	–	0.20
Singapore	–	0.19	–	–	0.19	–	0.18	0.23	–	0.18
Taiwan	0.23	0.18	0.21	–	0.19	0.20	0.21	0.04	–	0.19
Thailand	0.33	0.20	0.35	–	0.22	0.31	0.19	0.34	0.15	0.21

^aThe percentage carbon contents of coal is 38.8 for China (Shrestha and Acharya, 1992), 56.4 for Indonesia, 54.6 for India, 50.4 for Japan (Bhattacharya et al., 1994), 51 for South Korea (Bhattacharya et al., 1994), 40 for Pakistan (Bhattacharya et al., 1994), 35 for Thailand (Bhattacharya et al., 1994) and 54.6 for rest of the selected countries (Shrestha and Acharya, 1992). The percentage carbon contents of other fuels for all selected countries are 80 for fuel oil (Shrestha and Acharya, 1992) 86.9 for diesel and 63.1 for natural gas (Goto et al., 1993).

^bFor year 1982.

shows that the changes in CO₂ intensity of power generation, was mainly influenced by changes in fuel intensities of power generation rather than shifts in generation structure in most of the selected countries.

As can be seen from the figures, the fuel intensity effect was the major force behind the evolution of CO₂ intensity during 1980–1990 in eight Asian economies (China, South Korea, India, Indonesia, Japan, Pakistan, Singapore and Taiwan) while both fuel intensity and generation mix effects were influential in the case of Hong Kong. The changes in generation mix had the tendency to increase the CO₂ intensity in China during 1980–1986 but it was avoided by the significant improvements in generation efficiency during the period. Similarly, in Singapore, fuel intensity effect was decreasing sharply during 1980–1990 indicating technological improvements in power generation without which the CO₂ intensity could have increased as the effect of generation mix was to increase CO₂ intensity in that period.

Changes in CO₂ intensity in Malaysia were mainly influenced by the fuel intensity effect during 1980–1986 while both fuel intensity and generation mix effects were influential thereafter. In the Philippines, both fuel intensity and generation mix effects were sympathetic to changes in power sector CO₂ intensity during 1980–1986 while only the fuel intensity effect was responsible during 1985–1990. In the case of Thailand both fuel intensity and generation mix effects contributed to CO₂ intensity changes during 1980–1986, but it was only the

Table 5
Main factors affecting CO₂ emission intensity^a

Country /region	Periods	
	1980–85	1986–90
China	FIE	FIE
Hong Kong	Both	Both
India	FIE	FIE
Indonesia	FIE	FIE
Japan	FIE	FIE
South Korea	FIE	FIE
Malaysia	FIE	Both
Pakistan	FIE	FIE
Philippines	Both	FIE
Singapore	FIE	FIE
Taiwan	FIE	FIE
Thailand	Both	GME

^a FIE = fuel intensity effect, GME = generation-mix effect, Both = both effects.

generation mix effect thereafter. The findings on the factors influencing the CO₂ intensity during the period 1980–1986 and 1986–1990 are summarized in Table 5.

5. Conclusions and final remarks

The present analysis shows that in six of the selected countries, Japan, Hong Kong, Singapore, Malaysia South Korea, and Thailand, the CO₂ intensity exhibited a decreasing trend during 1980–1990. Only in the case of Pakistan, did the intensity increase during the period. In China and the Philippines, it remained almost unchanged while in the other economies (Taiwan, India, Indonesia), it had an erratic profile during the study period.

The fuel intensity effect was found to be mainly responsible for the changes in CO₂ intensity of electricity generation in 8 out of 12 selected Asian countries (China, South Korea, India, Indonesia, Japan, Pakistan, Singapore and Taiwan) during the entire study period and in one further country (Malaysia) during 1980–1986. Both fuel intensity and generation mix effects were influential in Hong Kong during 1980–1990, and in Malaysia and the Philippines during a part of the study period. A shift in generation mix was the main force behind the CO₂ intensity changes in the case of Thailand during 1986–1990.

It should be noted here that the quality of fuel has been assumed to remain unchanged during the study period primarily due to lack of the relevant time series data. Some variations in the result could be expected if the effects of changes in fuel quality during the period were formally included in the analysis. In particular, the effects due to changes in fuel quality are likely to be more substantial the longer the study period as diversification of fuel supply sources becomes more

likely. This highlights the importance of establishing a sound database on fuel quality for a more meaningful analysis of the role of various factors in the evolution of CO₂ emission intensity changes in the power sector.

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